THE OHIO STATE UNIVERSITY

SCHOOL OF EARTHSCIENCES

The Ohio State University School of Earth Sciences/Mineral Physics Research Group

# The Petrologist's Guide to the Galaxy

## A method for modeling terrestrial exoplanets using the MELTS algorithm

Scott D. Hull, Wendy R. Panero, and Cayman T. Unterborn

### 1. INTRODUCTION

**Recent technological advancements have led to the capability to detect exoplanets on a large scale. In particular, the search for "Earth-like" planets with the potential for life is currently restricted to little more than considering the average density of the planet and the distance from its star. Due to the inability to make more detailed direct measurements on these planets, there is a need for a method to model exoplanet chemistry and physical properties using indirect data. This study combines the MELTS code (Ghiorso & Sack, 1995) with a range of stellar spectroscopic compositions (Fig 1), representative of terrestrial exoplanet chemistry, in order to fulfil this need.**

**The Earth is unique in its steady state, surface-to-interior cycling of material through plate tectonics. We use our method to investigate the likelihood of a basalt-eclogite transition on a given exoplanet, producing evidence for plate tectonics and implications for the deep water cycle and potential habitability.**

### 2. GOALS AND METHODS

**Our method requires the completion of four steps in order to produce both the chemistry and physical properties of a terrestrial exoplanet in a given stellar system:**

- Benchmark the model of a "Bulk Silicate Earth" from the composition of a C1 chondrite (Lodders, 2003) in MELTS (Fig 2).
- Use this BSE composition to further benchmark the composition of primitive basalt in MELTS (Fig 3).
- Apply this benchmarked Earth model to stellar compositions in MELTS to calculate the system's "ExoBSP" and "ExoBasalt" composition. Core mass percentage is found as a consequence of this step.
- Use phase equilibrium thermodynamic-based code (HeFESTo) to determine exo-mineralogy and the likelihood of a basalt-eclogite transition (Fig 4).

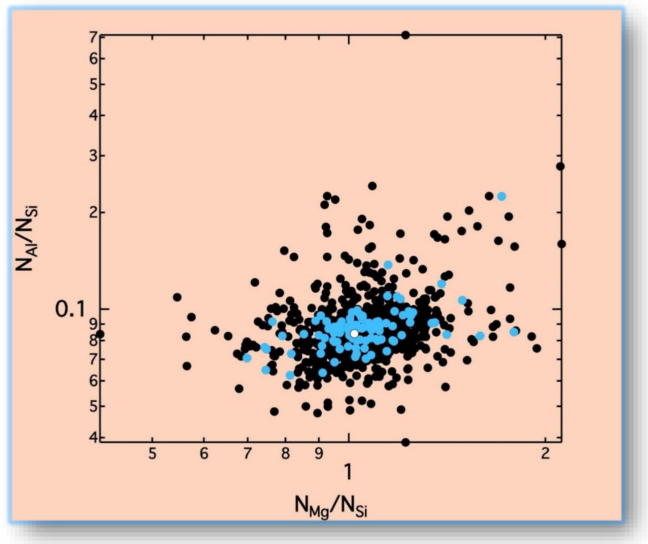



Figure 1: Molar ratios of (Mg/Si) versus (Al/Si) from the Adibekyan et al. (2012) stellar survey. Stars with confirmed planets are colored blue.

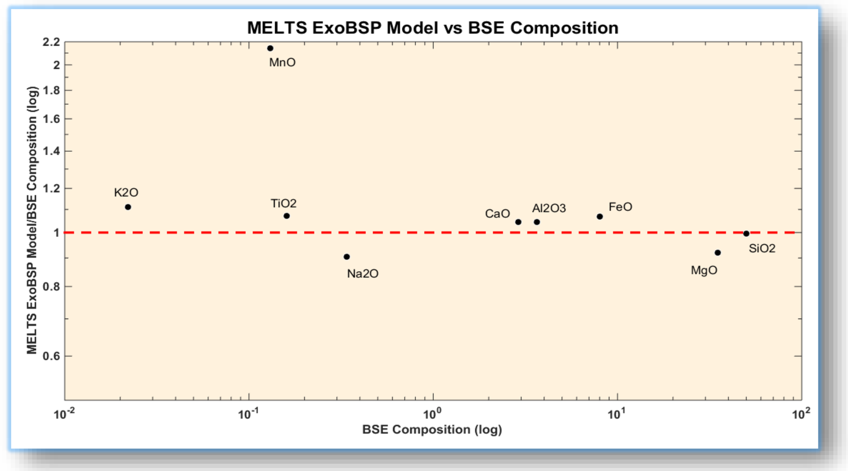



Figure 2: Our MELTS ExoBSP model vs. the C1 chondrite "Bulk Silicate Earth" model (McDonough & Sun, 1995).

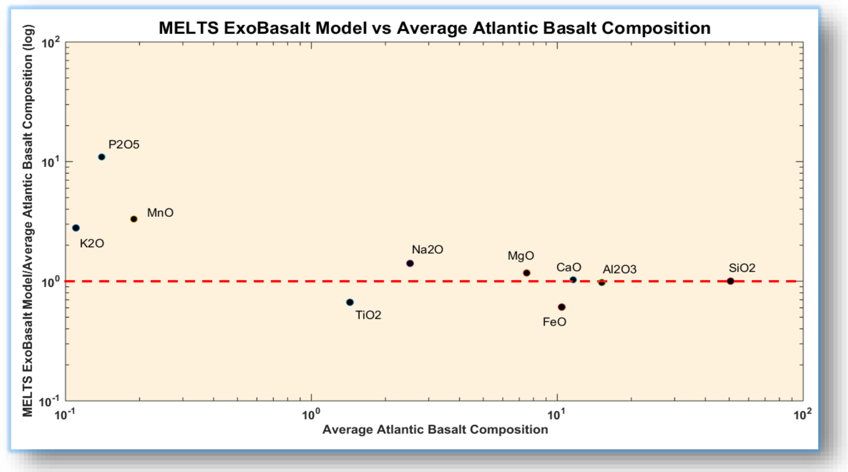



Figure 3: Our MELTS ExoBasalt model vs. an average Atlantic basalt composition (Perfit, 2001).

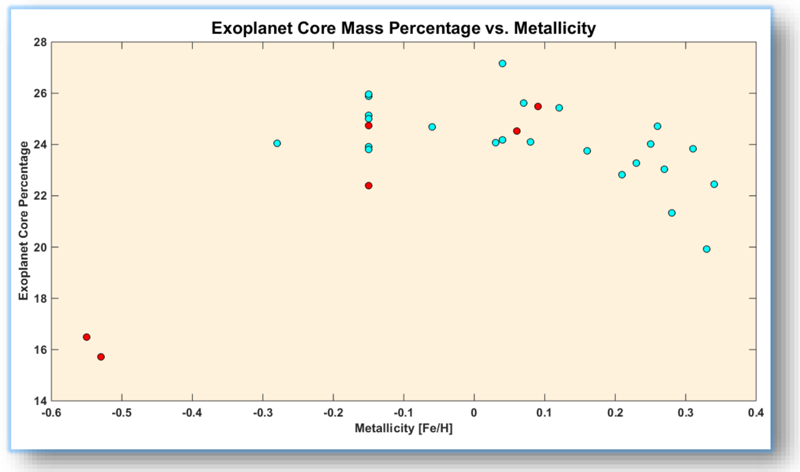



Figure 4: Exoplanet core mass percentages vs. metallicity for a range of stellar samples are shown in blue. The six samples used to calculate basalt-eclogite transitions are in red.

### 3. Results

**The application of our "ExoBSP" and "ExoBasalt" models to six stellar samples yields similar chemical to the Earth with regards to the major planet-building oxides ($SiO_2$, $Al_2O_3$, FeO, MgO, CaO). There is more variation in the "ExoBasalt" model than the "ExoBSP" model, but basalt can differ within a range of chemistry (Fig 5). By subtracting out iron-nickel alloy generated from the "ExoBSP" model, we mimic the removal of a core and can compare its mass to the starting mass to get a core mass percentage (Fig 4).**

**Densities of the MELTS generated basalt (ExoBasalt) versus the generated mantle (ExoBSP) can be calculated with the HeFESTo phase equilibrium code as a function of depth (Fig 6). Two modeled planetary systems have basalt densities that become greater than the mantle density with depth (HD181720, HD51754). This is where basalt would begin to sink in mantle and create the "slab pull" effect we see in plate tectonics. Some of the samples show results for both an artificial increase in aluminum and an artificial decrease in sodium. This is due to constraints in the HeFESTo code database used to model density changes for basalts with exotic chemistries, specifically where Na/Al>1. A decrease in the amount of volatile sodium is the more realistic option for a planetary body.**

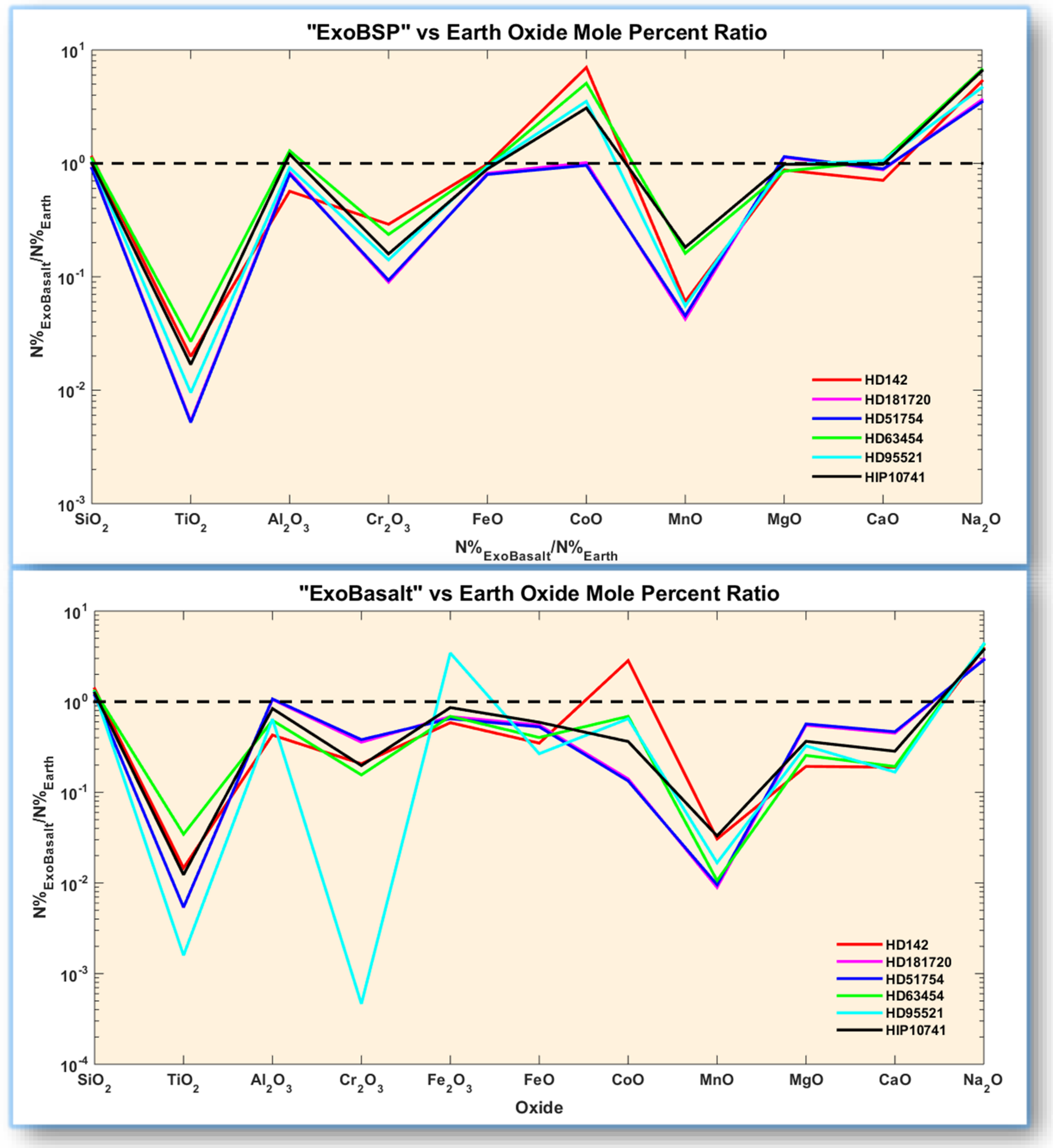



Figure 5: The "ExoBSP" and "ExoBasalt" vs Earth oxide mole percent ratios for six sample stars.

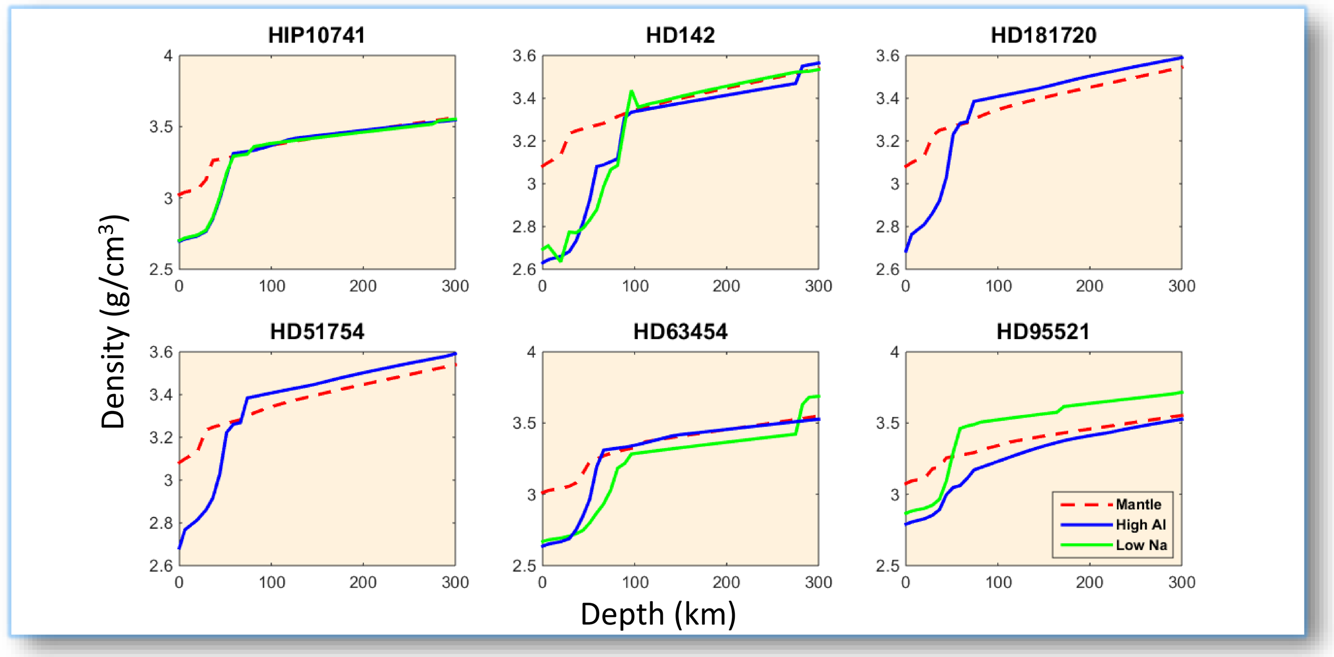


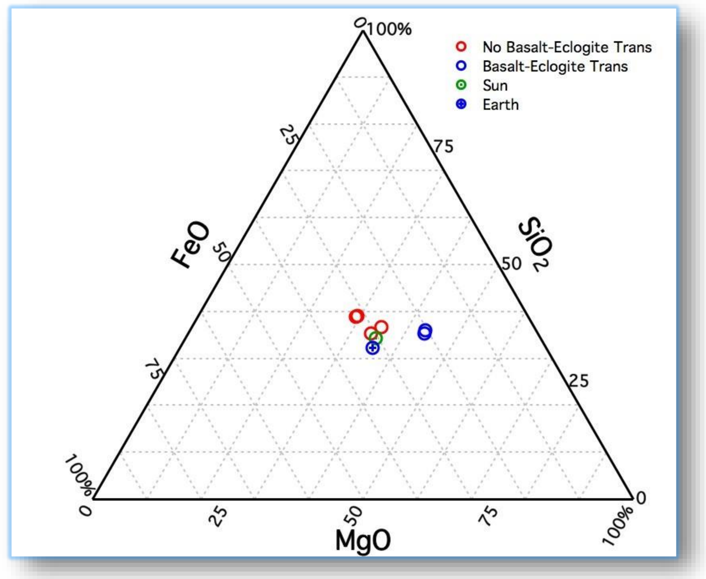

Figure 6: HeFESTo code output simulating mantle and basalt density as a function of depth. An increase of basalt density over mantle density in HD181720 and HD51754 signifies that a basalt-eclogite transition could drive plate tectonics on an average terrestrial planet in that system.

### 4. Conclusions and Future Work

**Using stellar compositions paired with thermodynamic modeling, this study is a viable method for modeling exoplanet interior mineralogy. We apply this method to understand the likelihood of basalt-eclogite transitions taking place within the mantles of these planets. Without these transitions, the likelihood of plate tectonics and the associated implications with the deep water cycle, long-term carbon regulation, and habitability is severely decreased.**

**Limitations in the Earth-suited MELTS database have created instabilities when modeling exotic chemical compositions found within our sample stars. As our study progresses, we will work on stabilizing the calculations done on stellar compositions that fall within the MELTS database. With this improved model, we will constrain which stellar major element chemistries allow for planets that will undergo basalt-eclogite transitions, and thus be potentially habitable for life as we know it.**

Figure 7: A ternary diagram showing the initial major oxides of stellar chemistries that did and did not clearly allow for a basalt-eclogite transition in six samples.

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